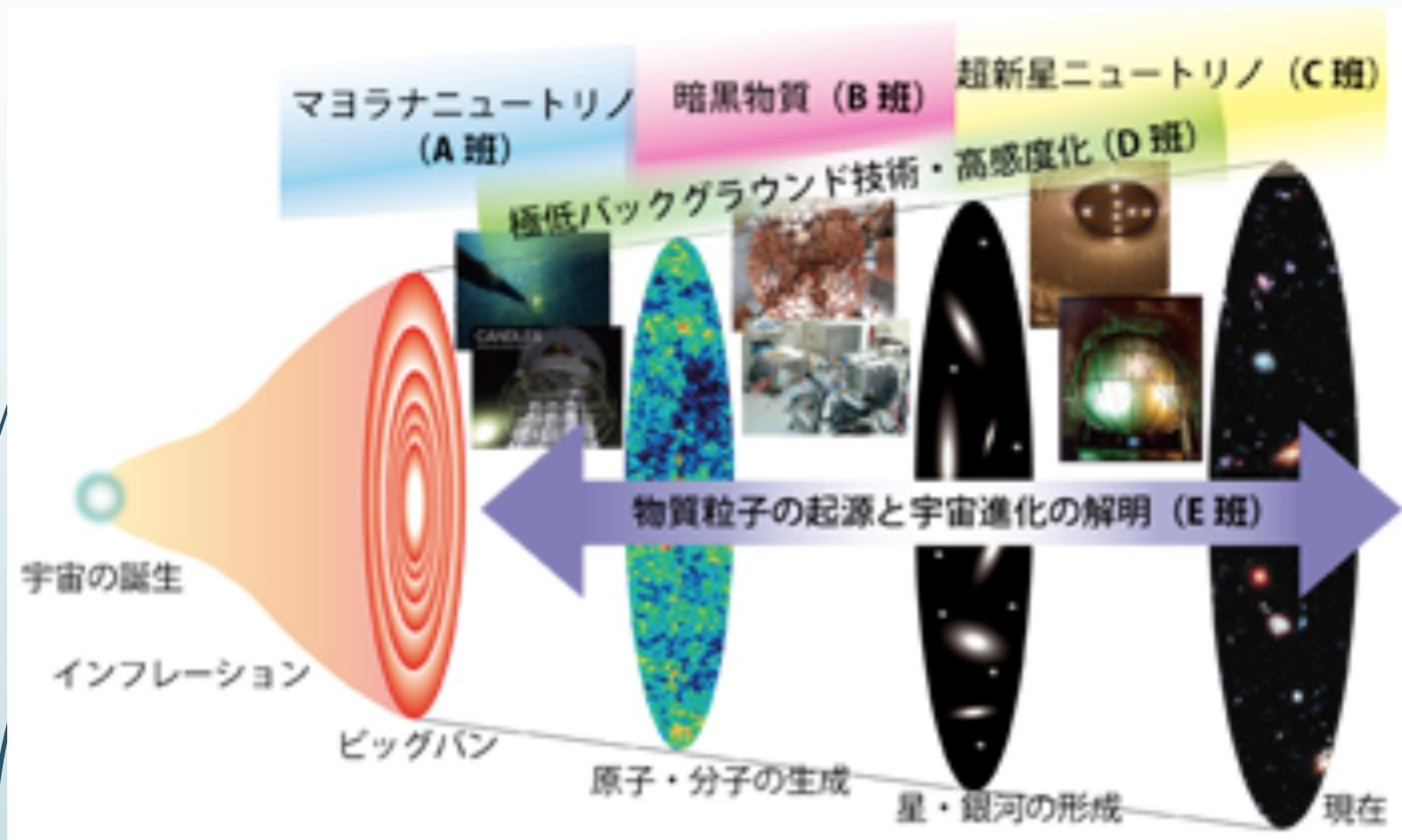


地下素核研究 B01 「大型検出装置による 暗黒物質直接探索」

岸本 康宏 for XMASS collaboration

於：2017年5月 岡山大学

領域全体の中の位置づけ

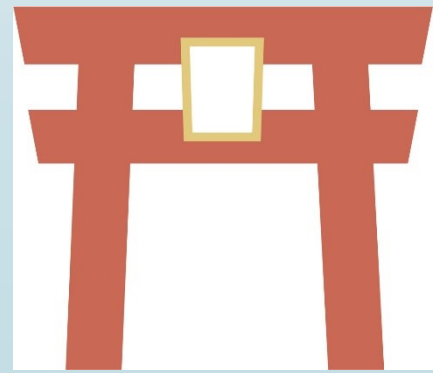


暗黒物質の発見により，宇宙の歴史を解明する



B01の2本の柱

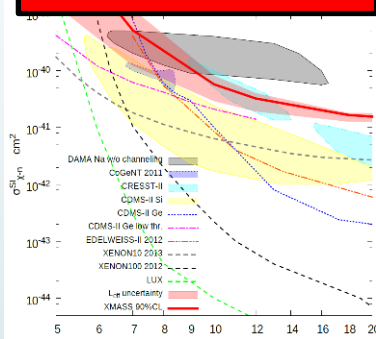
- 現在のXMASS実験装置を用いた暗黒物質探索
- 将来の大型暗黒物質探索装置のための開発・研究
 - 特に低バックグラウンド化



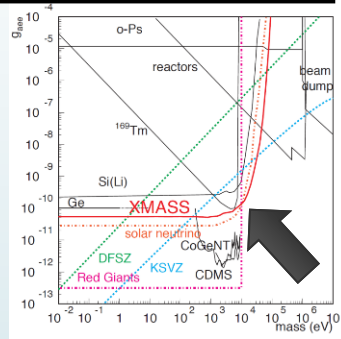
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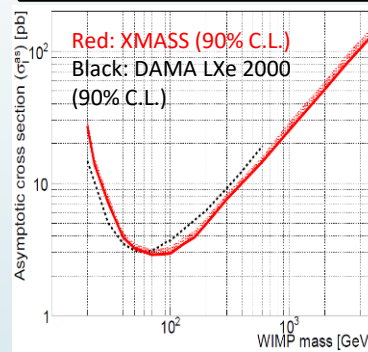
Low mass WIMPs search, PLB 719 (2013) 78



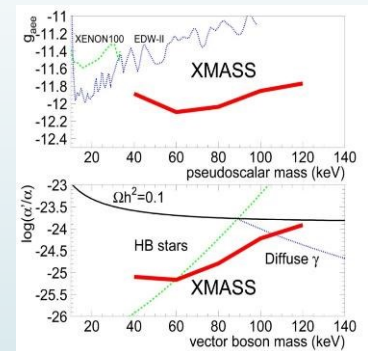
Solar axion search, PLB 724 46 (2013)



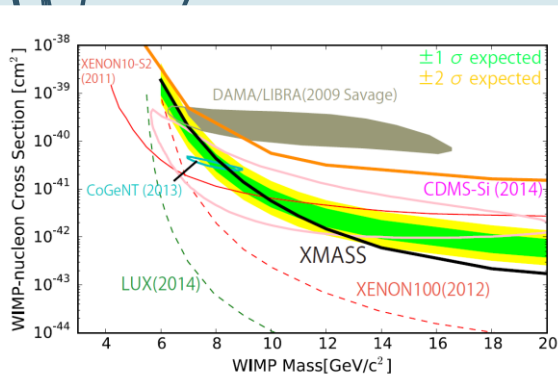
Inelastic WIMP nucleus scattering search, PTEP 063C01 (2014)



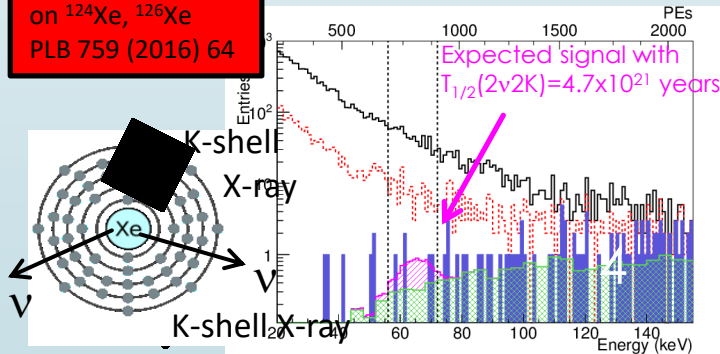
Bosonic super-WIMPs search, PRL 113, 121301 (2014)



Annual modulation, PLB 759 (2016) 272

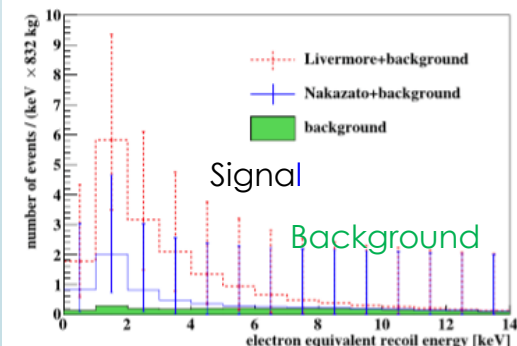


Search for 2ν 2EC on ^{124}Xe , ^{126}Xe PLB 759 (2016) 64



Possibility of supernova neutrino detection, Astropart. Phys. 89 (2017) 51

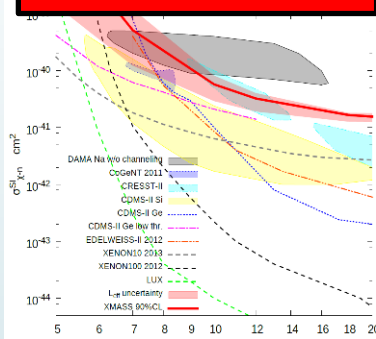
Supernova at 10kpc



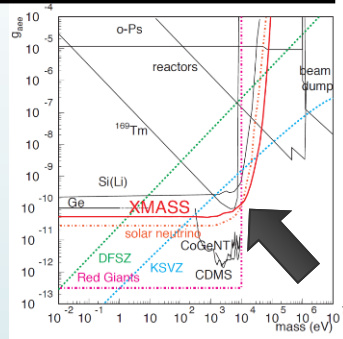
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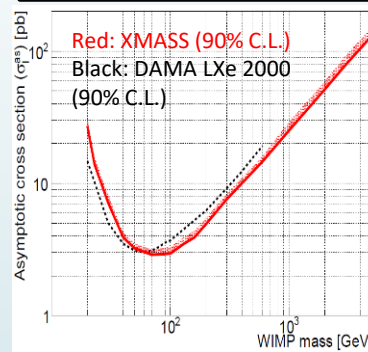
Low mass WIMPs search, PLB 719 (2013) 78



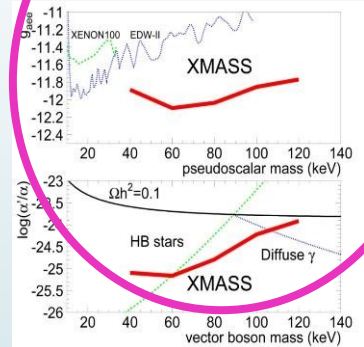
Solar axion search, PLB 724 46 (2013)



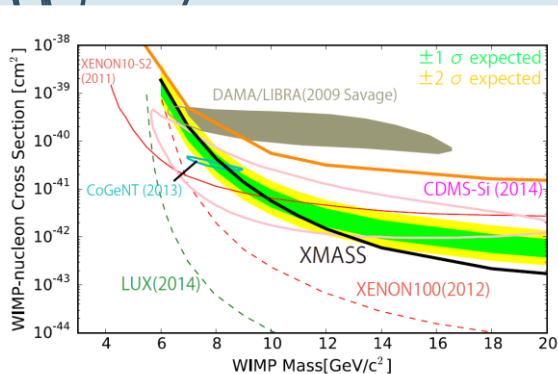
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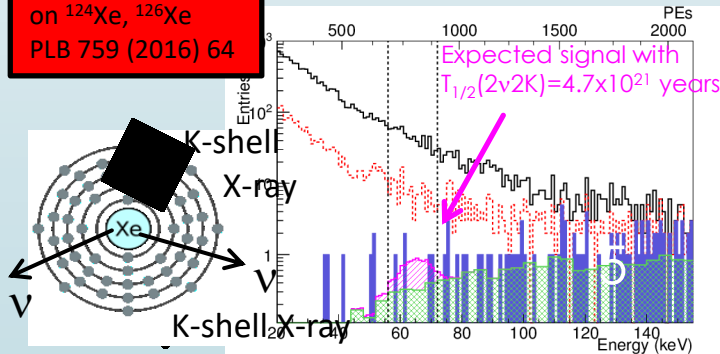
Bosonic super-WIMPs search, PRL 113, 121301 (2014)



Annual modulation, PLB 759 (2016) 272

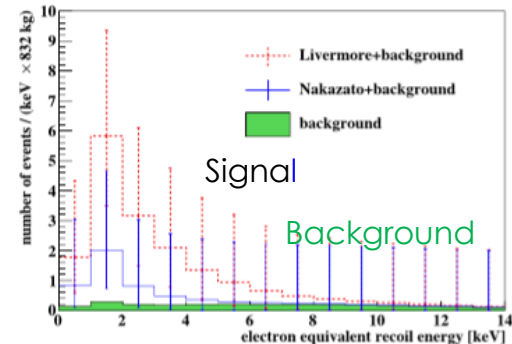


Search for 2ν 2EC on ^{124}Xe , ^{126}Xe PLB 759 (2016) 64



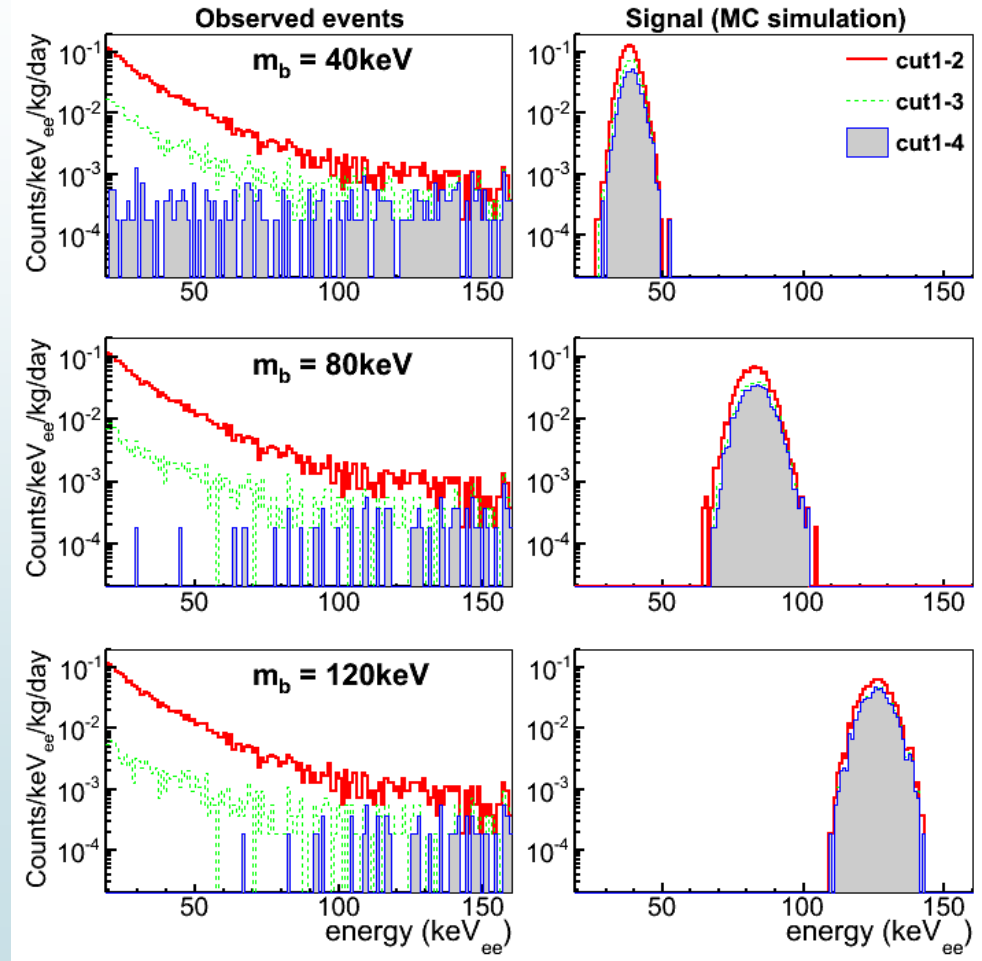
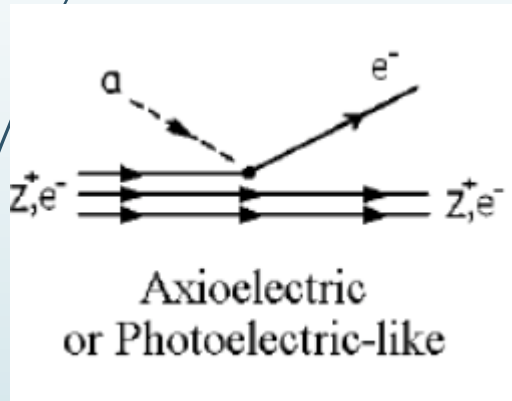
Possibility of supernova neutrino detection, Astropart. Phys. 89 (2017) 51

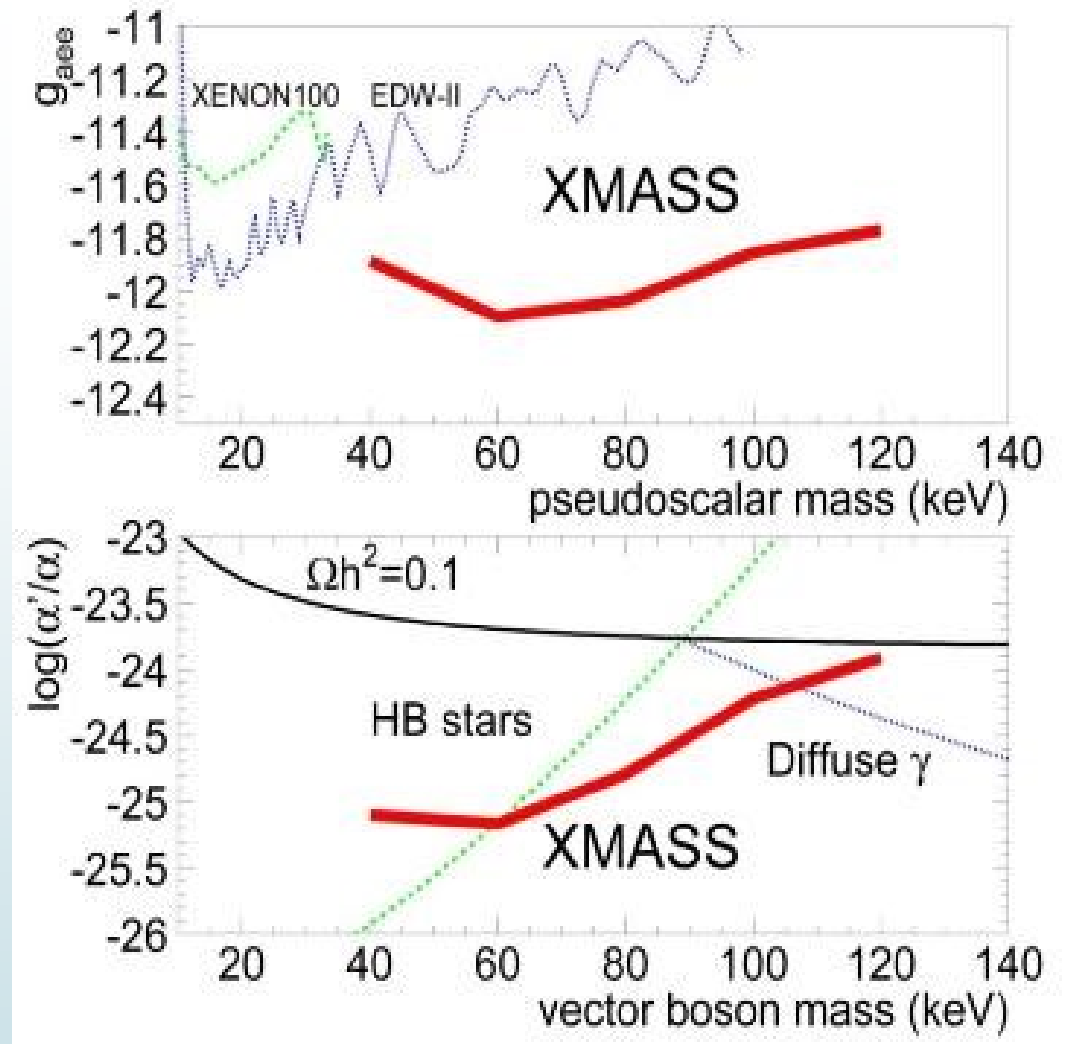
Supernova at 10kpc



Bosonic Super-WIMPs

A warm DM candidate



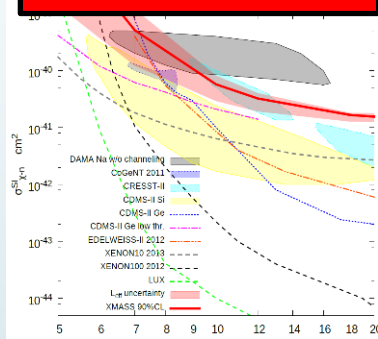


- ▶ ベクトル型の場合，熱的生成シナリオを否定

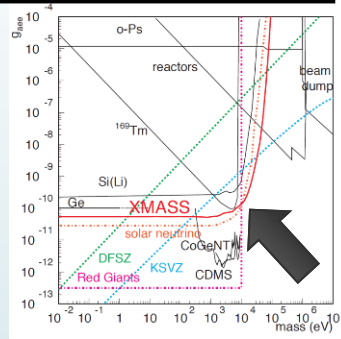
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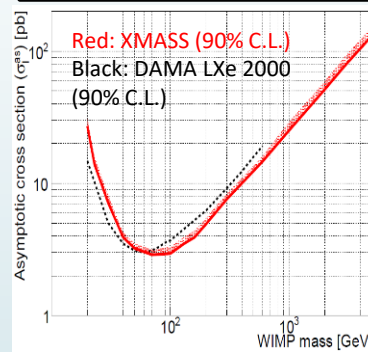
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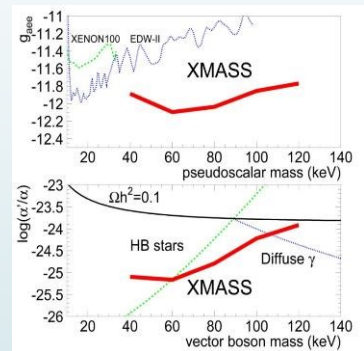
Solar axion search, PLB 724 46 (2013)



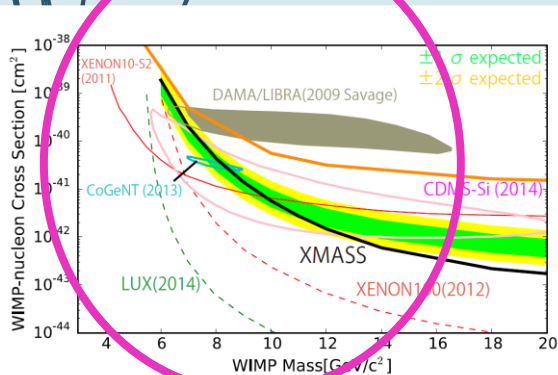
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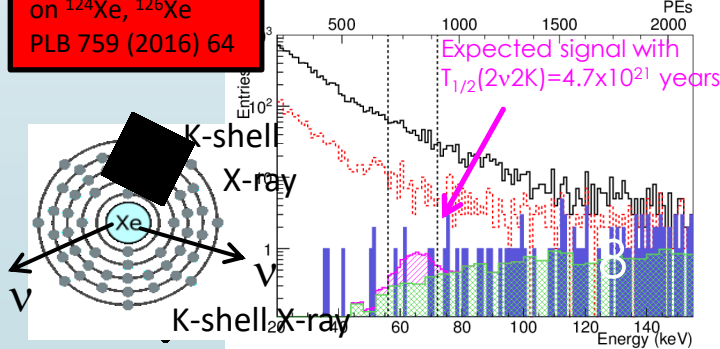
Bosonic super-WIMPs search, PRL 113, 121301 (2014)



Annual modulation, PLB 759 (2016) 272

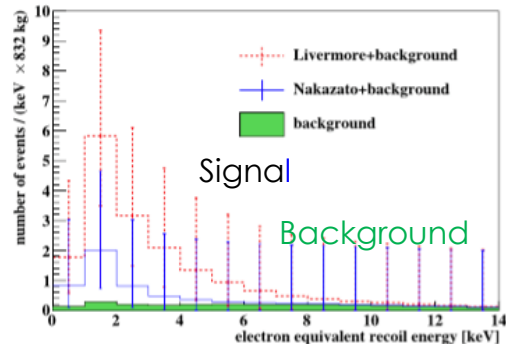


Search for 2ν 2EC on ^{124}Xe , ^{126}Xe PLB 759 (2016) 64

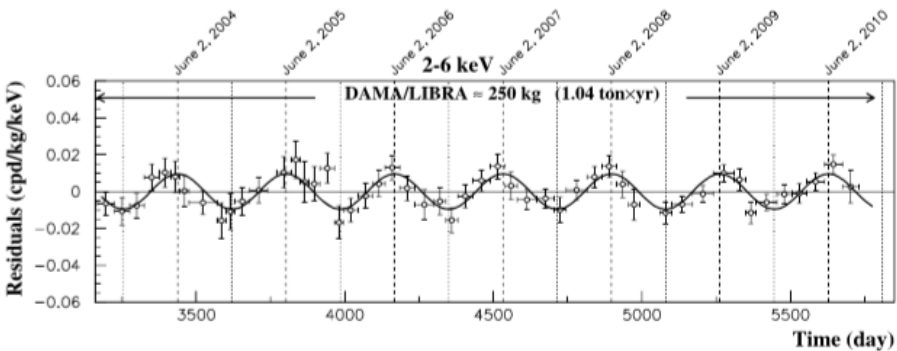
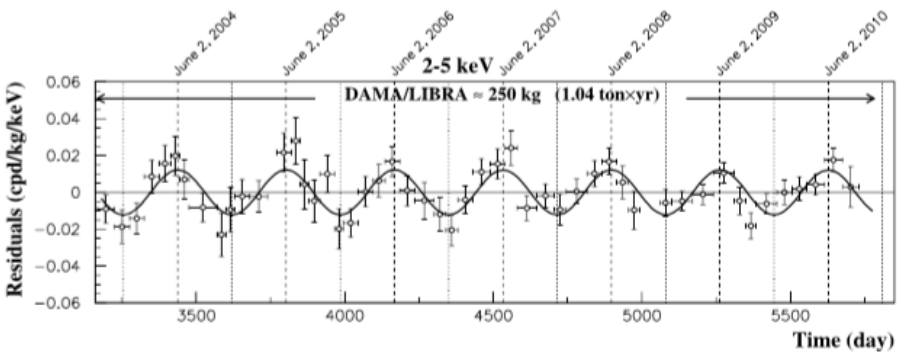
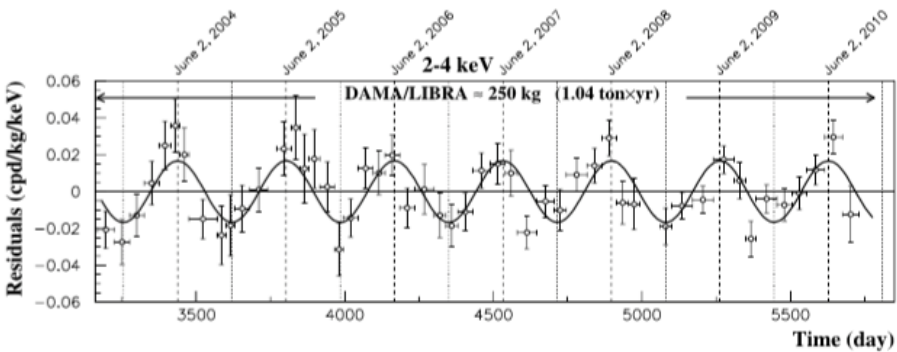


Possibility of supernova neutrino detection, Astropart. Phys. 89 (2017) 51

Supernova at 10kpc



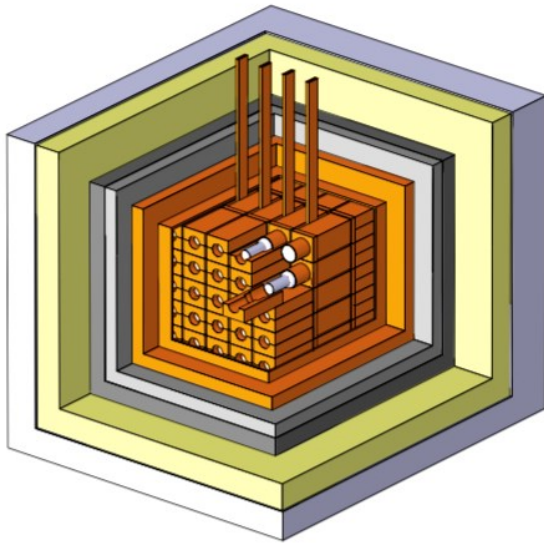
Annual modulation by DAMA/LIBRA



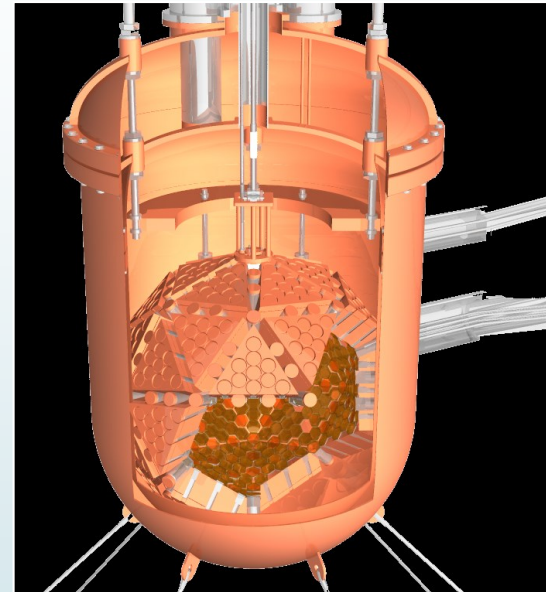
3 Conclusions

The data of the new DAMA/LIBRA-7 annual cycle have further confirmed a peculiar annual modulation of the *single-hit* events in the (2–6) keV energy region satisfying all the many requirements of the DM annual modulation signature; the cumulative exposure by the former DAMA/NaI and DAMA/LIBRA–phase I is 1.33 ton × yr.

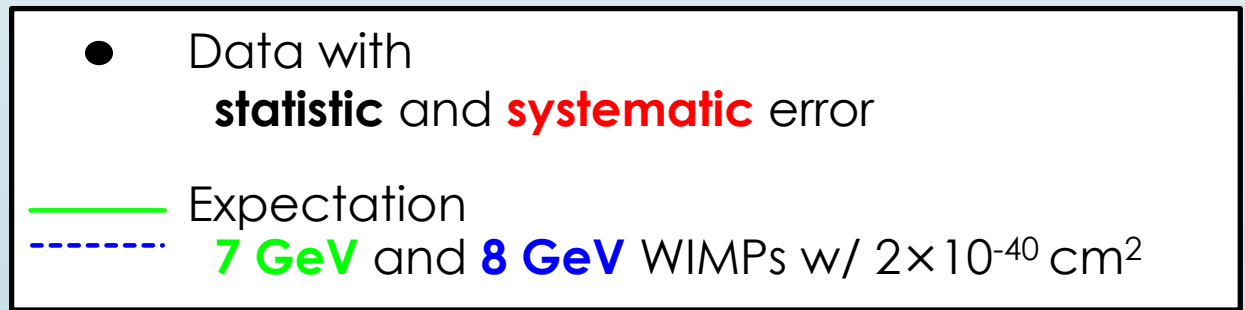
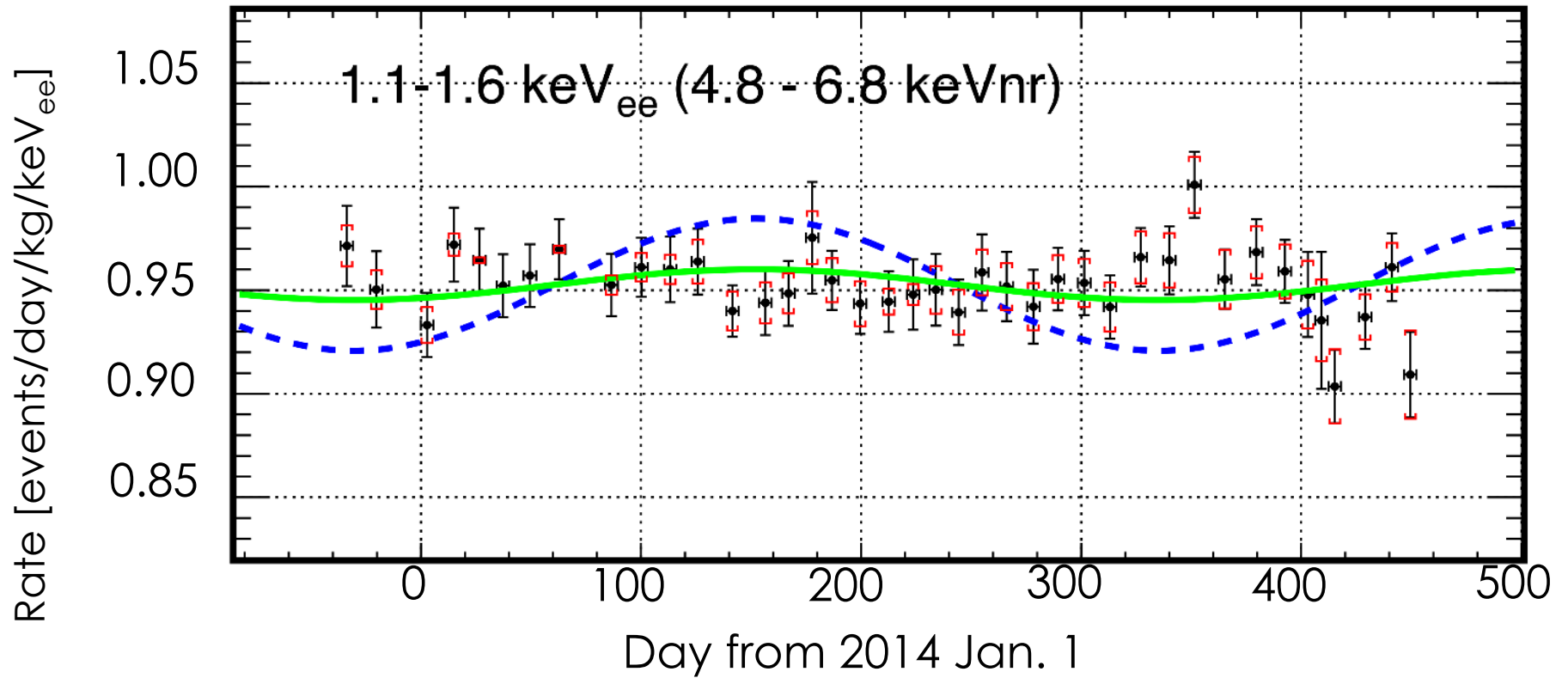
XMASSとDAMA/LIBRA






2 5 0 kg NaI(Tl) シンチレータ
No particle ID
1.33 ton*year

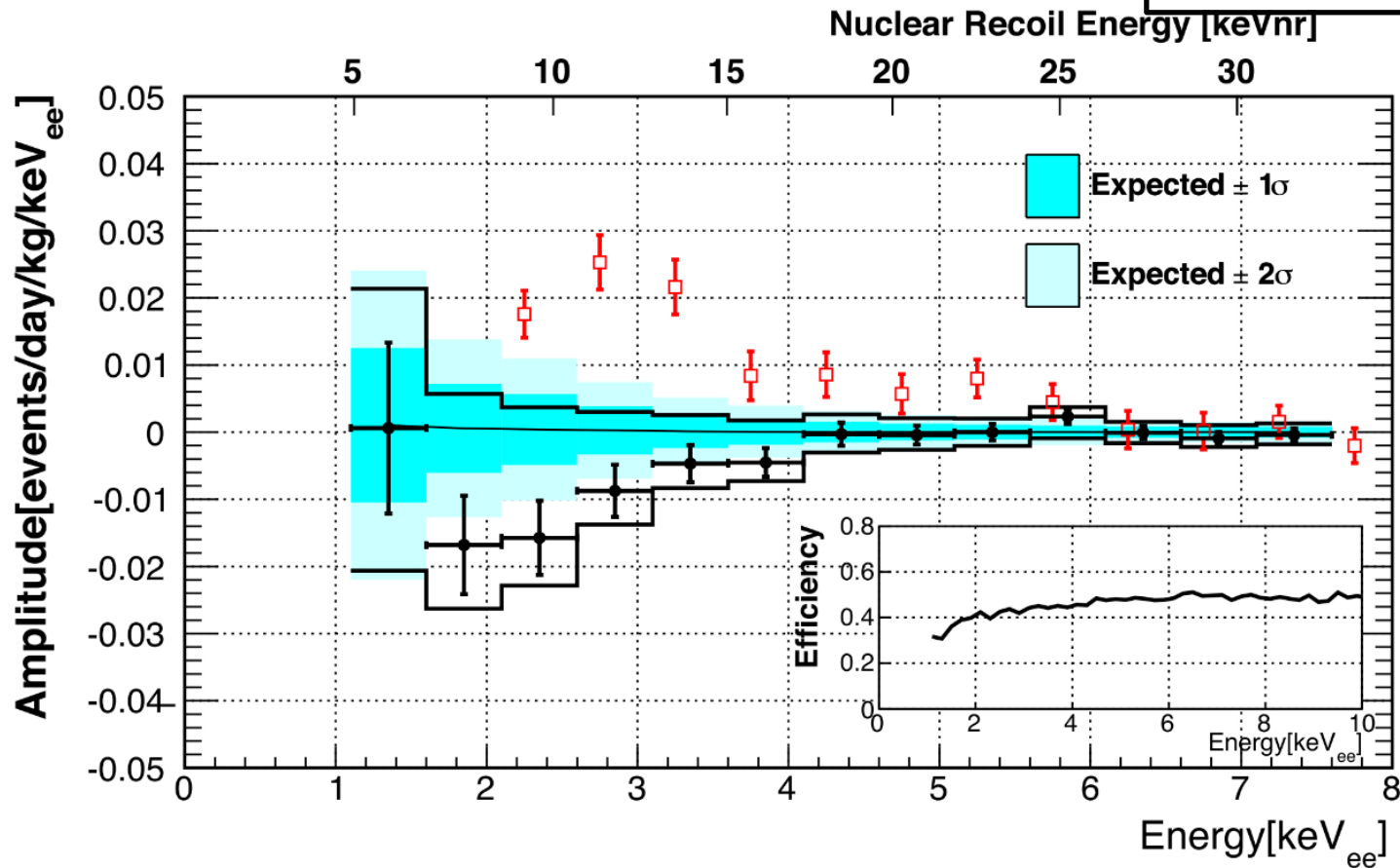


8 3 2 kg Xe シンチレータ
No particle ID
0.82 ton*year (Nov. 2013 → Mar. 2015)



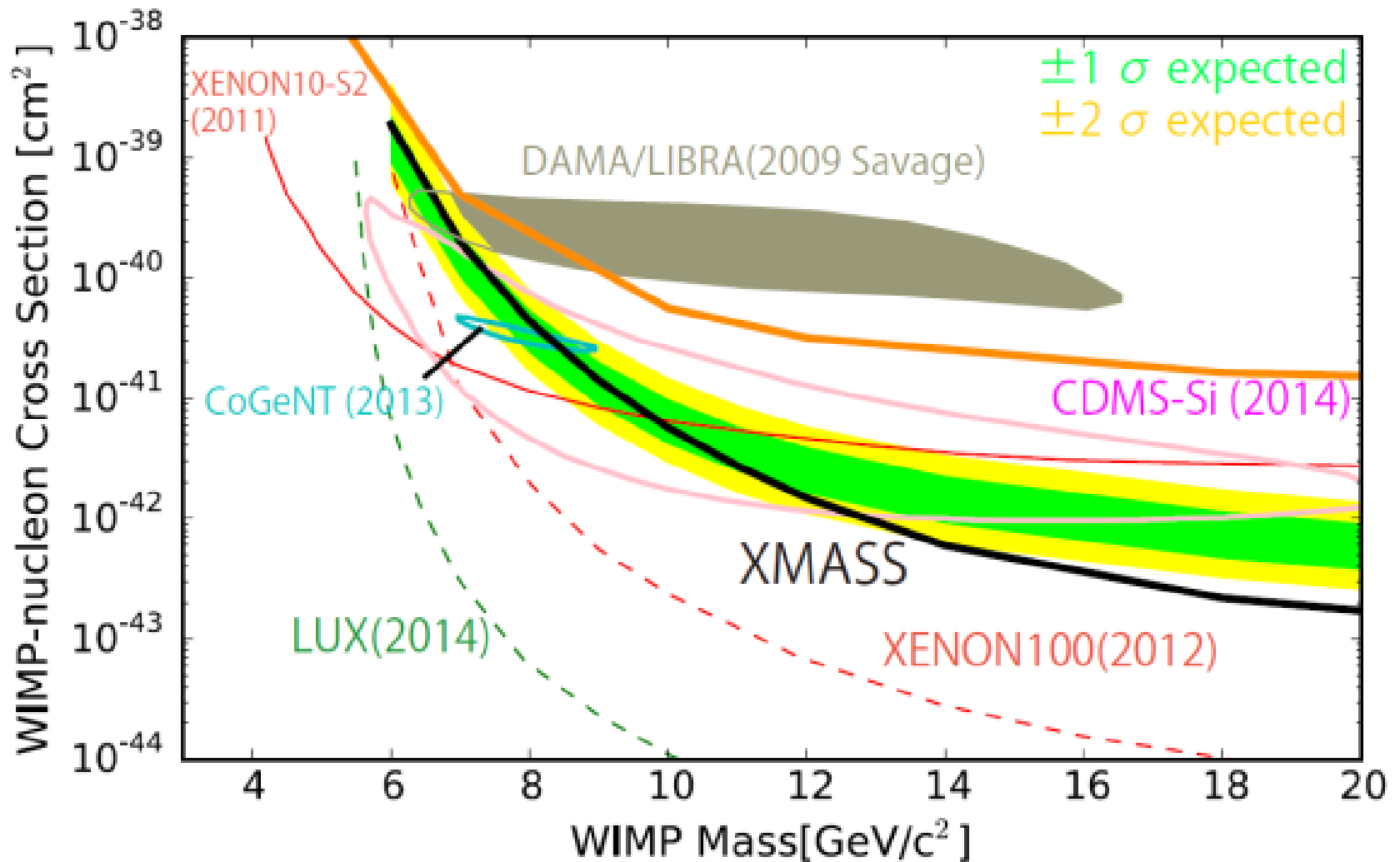
$$R_{i,j}^{\text{ex}} = \int_{t_j - \frac{1}{2}\Delta t_j}^{t_j + \frac{1}{2}\Delta t_j} \left(C_i + A_i \cos 2\pi \frac{(t - t_0)}{T} \right) dt,$$

-  XMASS
-  90% C.L. positive and negative upper limits
-  DAMA/LIBRA



同じ相互作用チャンネル, ほぼ同等の統計量で,
同じ事象 (季節変動) を検証

季節変動は見られなかった.

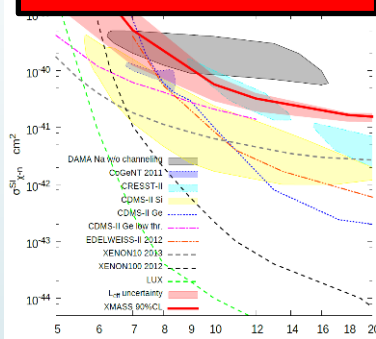


標準的な暗黒物質モデルを仮定した場合、
DAMA/LIBRAの領域のほとんどを排除

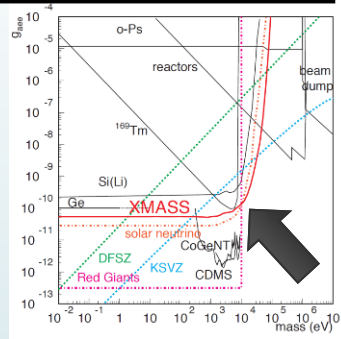
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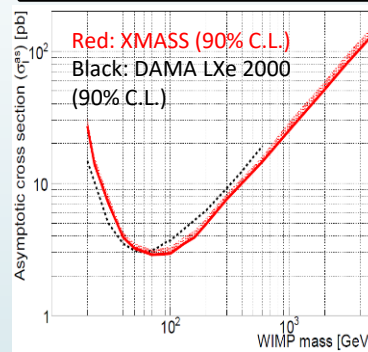
Low mass WIMPs search, PLB 719 (2013) 78



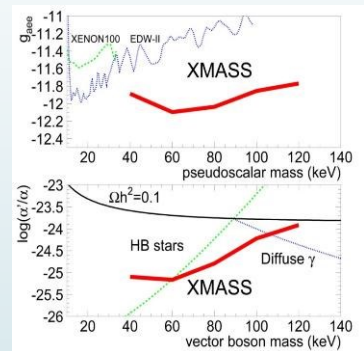
Solar axion search, PLB 724 46 (2013)



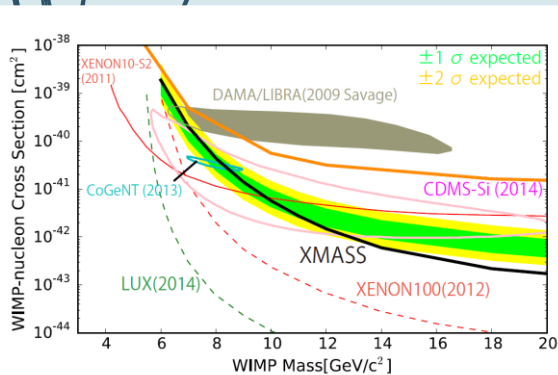
Inelastic WIMP nucleus scattering search, PTEP 063C01 (2014)



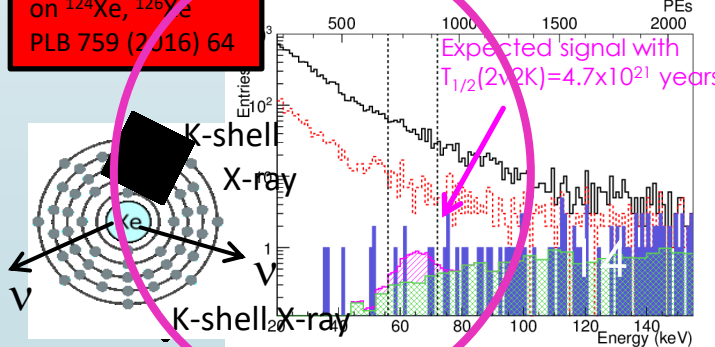
Bosonic super-WIMPs search, PRL 113, 121301 (2014)



Annual modulation, PLB 759 (2016) 272

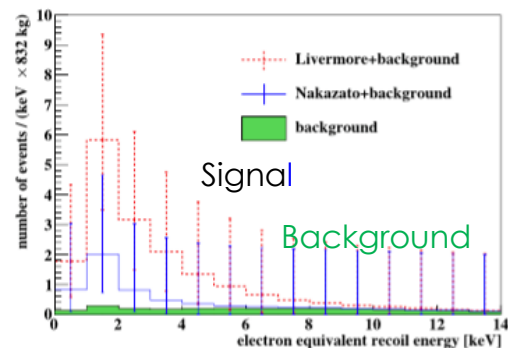


Search for $2\nu 2\beta\beta$ on ¹²⁴Xe, ¹²⁶Xe PLB 759 (2016) 64

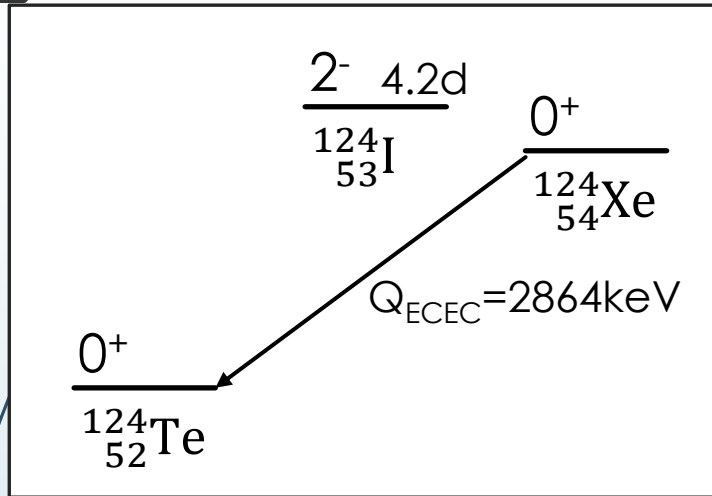


Possibility of supernova neutrino detection, Astropart. Phys. 89 (2017) 51

Supernova at 10kpc



2 ν double EC search

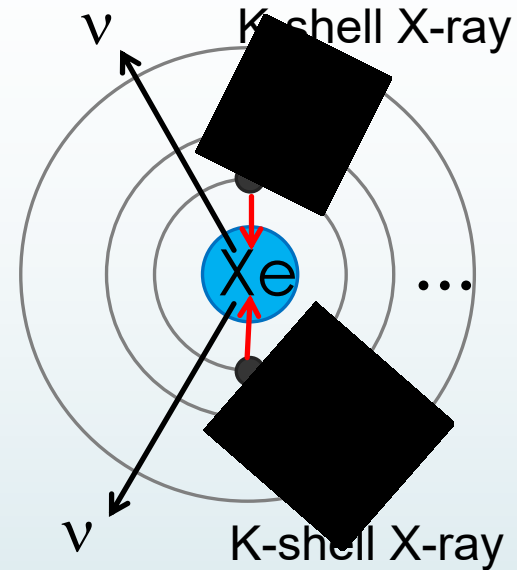


NA of $^{124}\text{Xe} = 0.095\%$



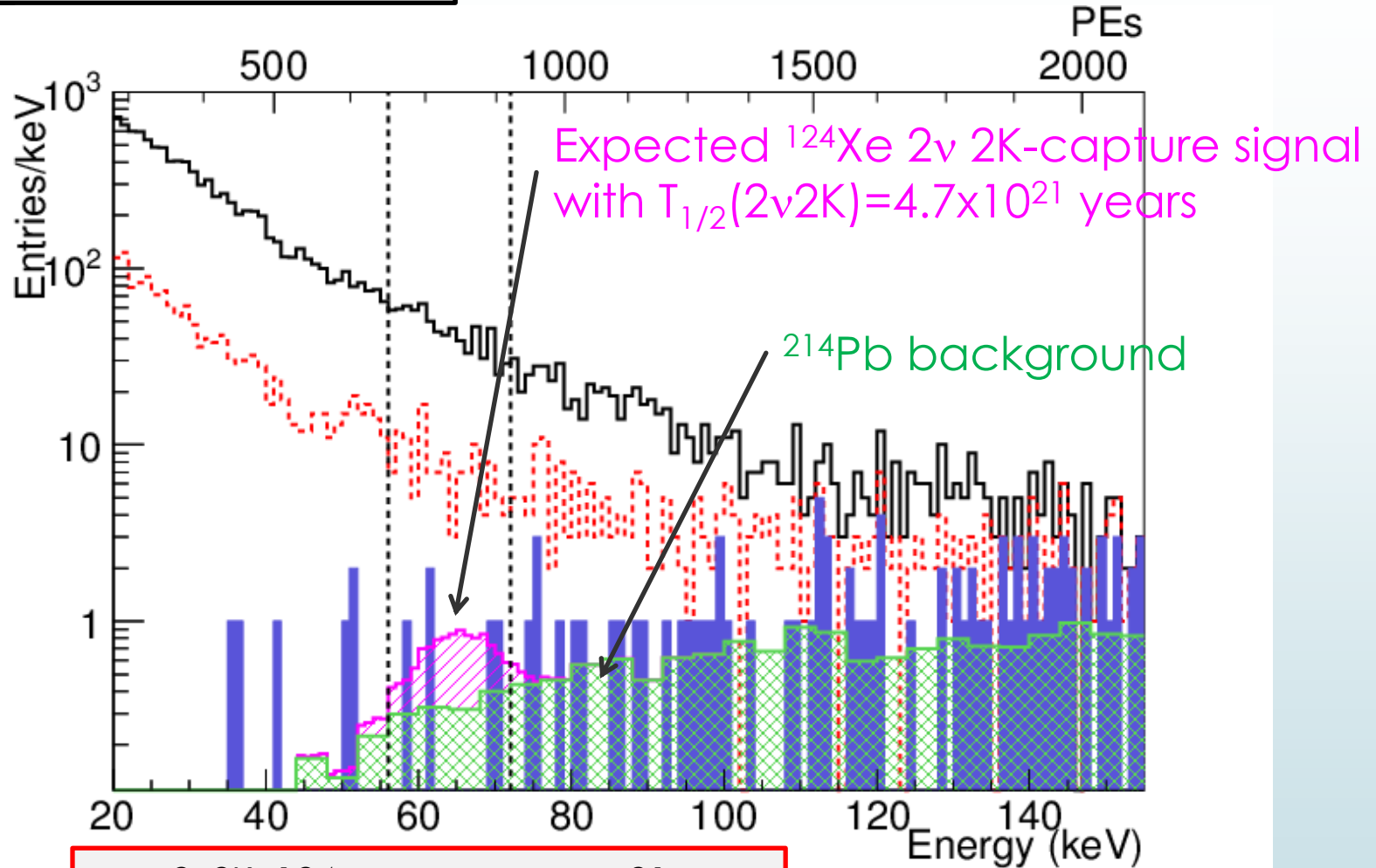
^{126}Xe (NA=0.089%) も同様 (但しQ=896 keV)

- ▶ 寿命の測定は、原子核行列要素計算に重要なデータとなる
 - ▶ Expected half-life is 10^{20} - 10^{24} years
- ▶ 0ν のモードならレプトン非保存



XMASSでも二重ベータ崩壊を通じて、宇宙の歴史に迫ることが可能

- Fiducial volume cut
- Timing cut
- Band-like pattern cut



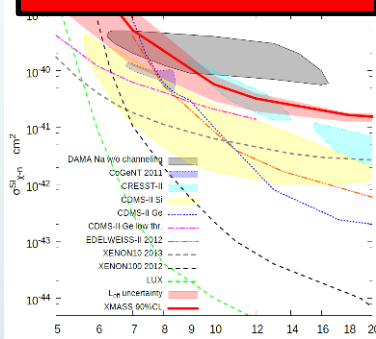
$T_{1/2}^{2\nu 2K}(^{124}\text{Xe}) > 4.7 \times 10^{21} \text{ y}$
 $T_{1/2}^{2\nu 2K}(^{126}\text{Xe}) > 4.3 \times 10^{21} \text{ y}$
 (90%CL)

The world best limits to date !!

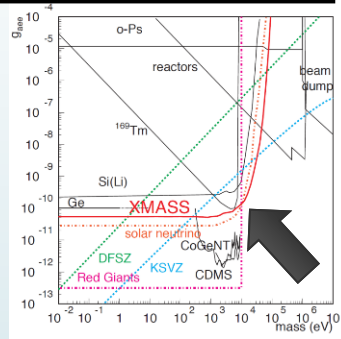
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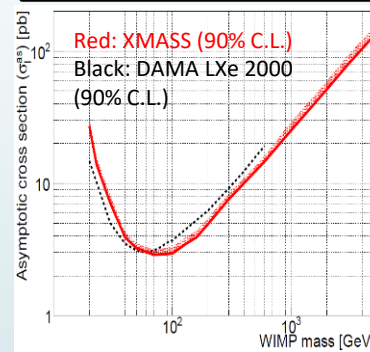
Low mass WIMPs search, PLB 719 (2013) 78



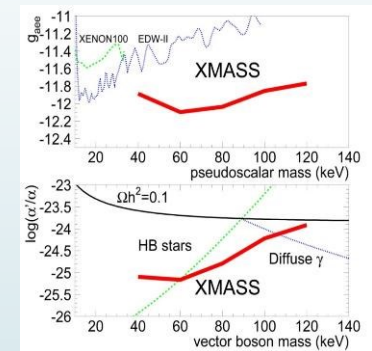
Solar axion search, PLB 724 46 (2013)



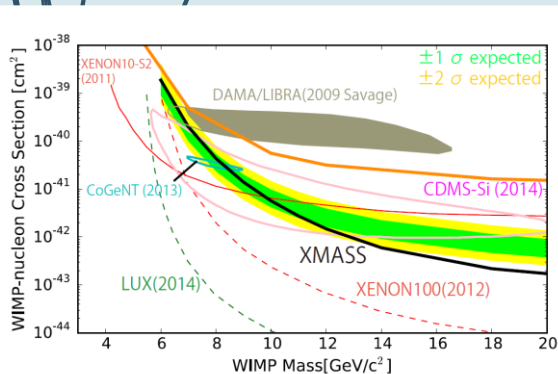
Inelastic WIMP nucleus scattering search, PTEP 063C01 (2014)



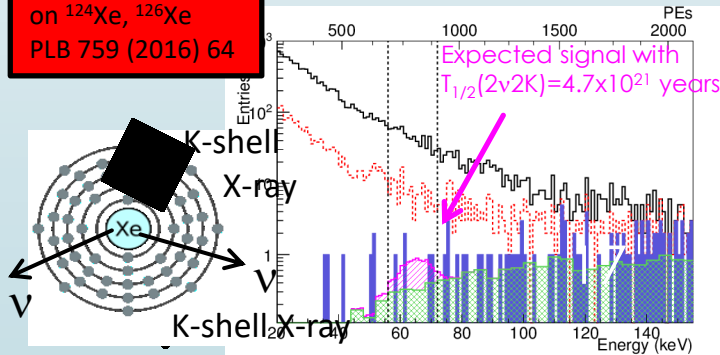
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Annual modulation, PLB 759 (2016) 272

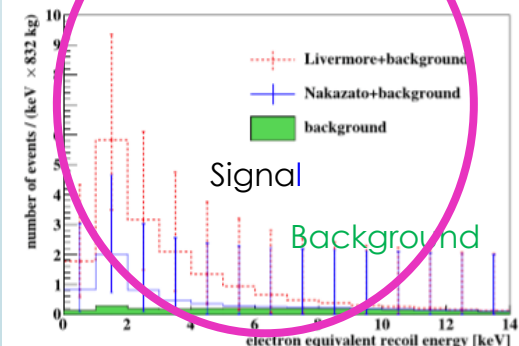


Search for 2 ν 2EC on ¹²⁴Xe, ¹²⁶Xe PLB 759 (2016) 64



Possibility of supernova neutrino detection, Astropart. Phys. 89 (2017) 51

Supernova at 10kpc



XMASSによるSN ν 観測の可能性

- ▶ 銀河内での超新星爆発のニュートリノ検出を検討
 - ▶ 超新星爆発のモデルは、中里さんの数値データを使用
 - ▶ 10.1088/0067-0049/205/1/2
- ▶ 検出はコヒーレント散乱過程
 - ▶ コヒーレント散乱は確実と思われるが、未確認
 - ▶ 全てのニュートリノに感度有

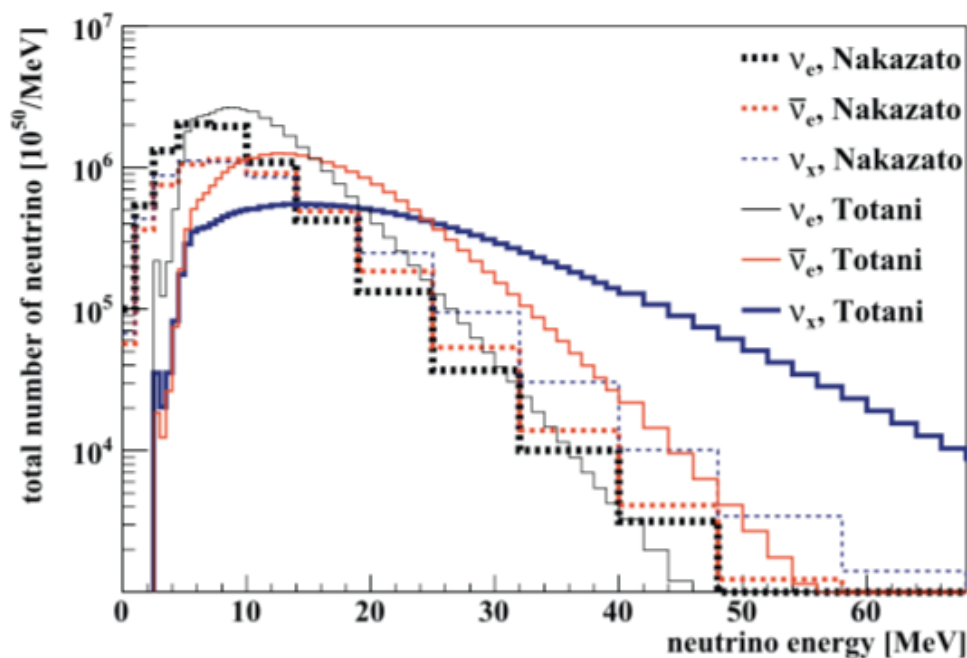
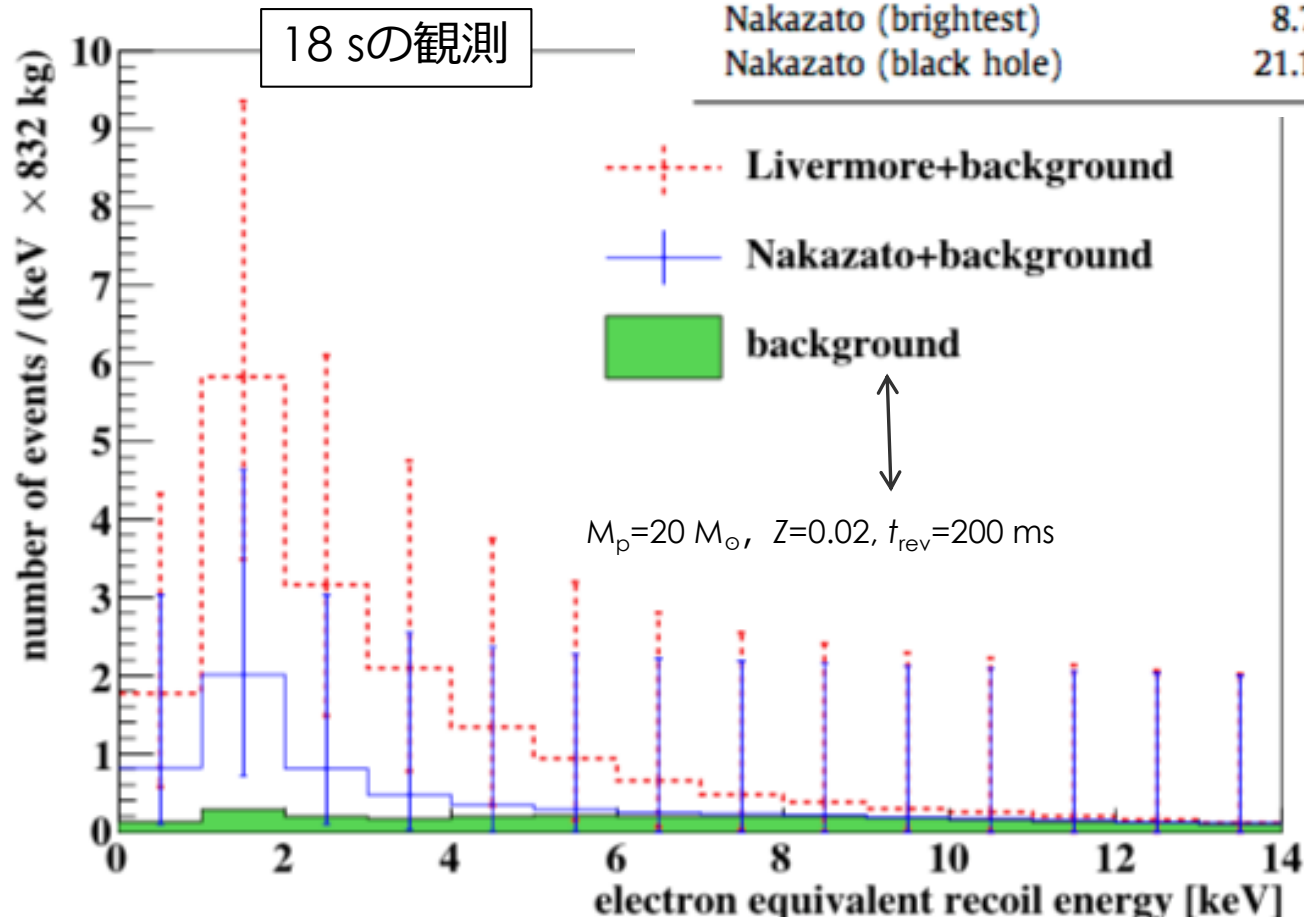


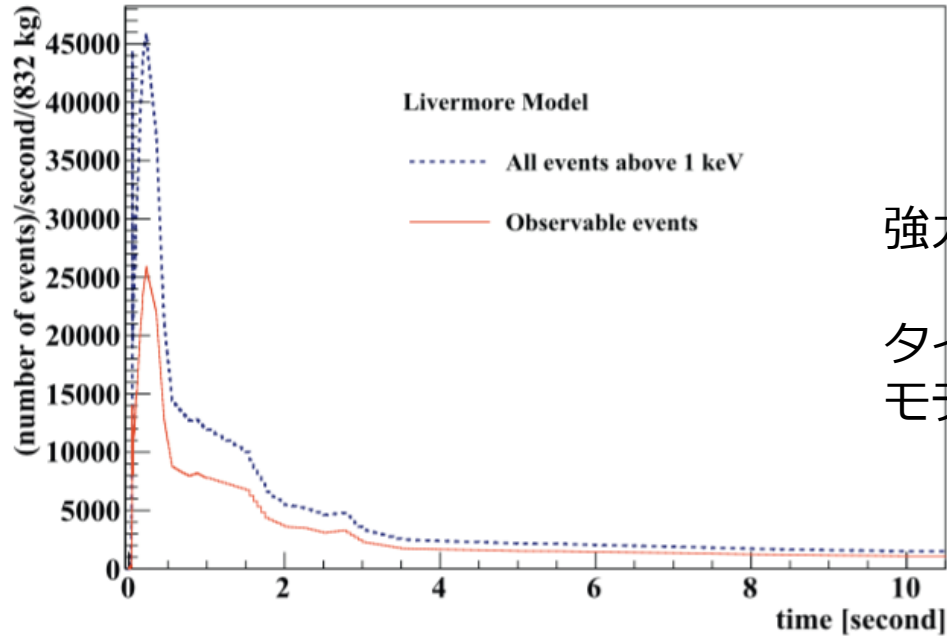
Table 2

Number of observable supernova events in XMASS. The weakest Nakazato model is the one with $M_p = 20 M_\odot$, $Z = 0.02$ and $t_{\text{rev}} = 100$ ms. The brightest Nakazato model is the one with $M_p = 30 M_\odot$, $Z = 0.02$ and $t_{\text{rev}} = 300$ ms. The black-hole-forming model is the one with $M_p = 30 M_\odot$, $Z = 0.004$. Neutrino energy spectra used in the calculation are all integrated from core collapse till about 18 s later.

Supernova model	$d = 10$ kpc	$d = 196$ pc
Livermore	15.2	3.9×10^4
Nakazato (weakest)	3.5	0.9×10^4
Nakazato (brightest)	8.7	2.3×10^4
Nakazato (black hole)	21.1	5.5×10^4

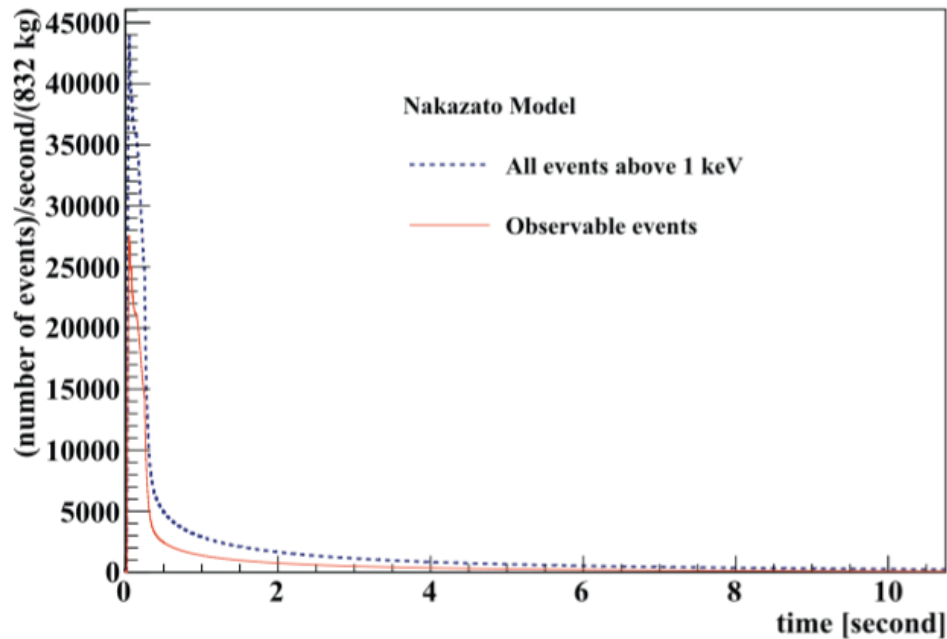


ベテルギウスなら



強力なDAQ系が必要

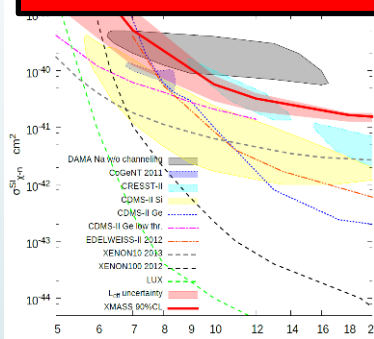
タイムスペクトルから、
モデルの選別も



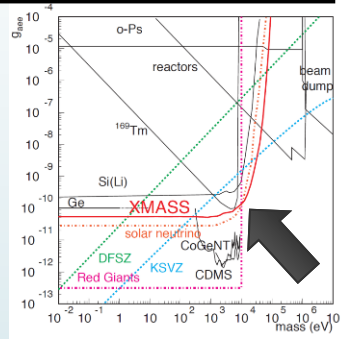
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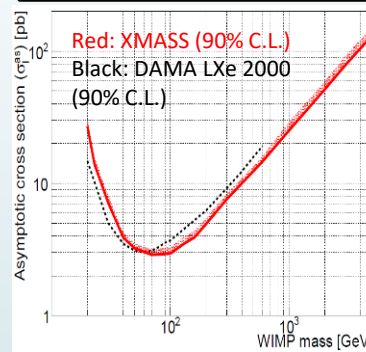
Low mass WIMPs search, PLB 719 (2013) 78



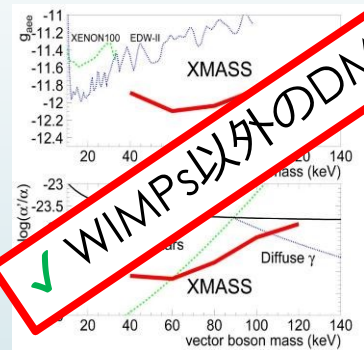
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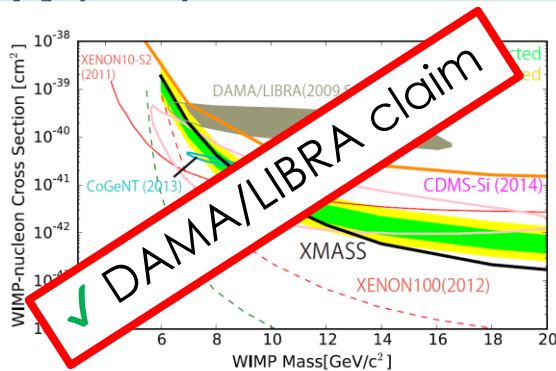
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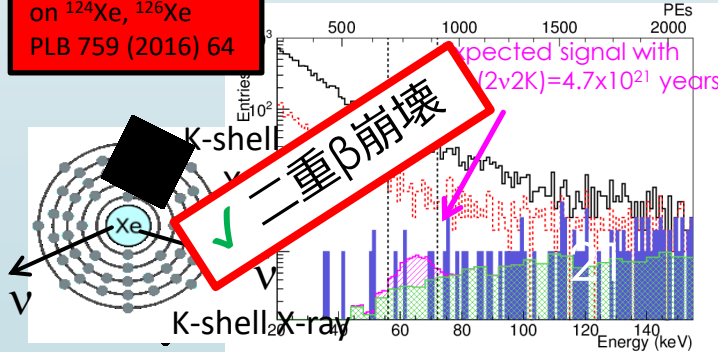
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Annual modulation, PLB 759 (2016) 272

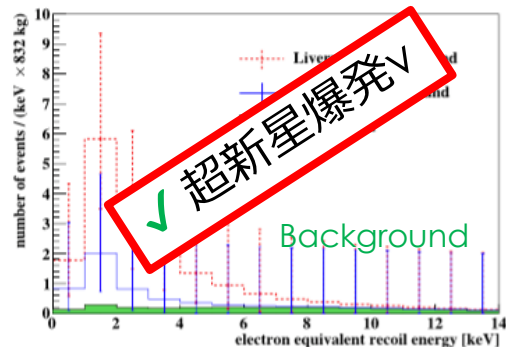


Search for 2ν 2EC on ^{124}Xe , ^{126}Xe PLB 759 (2016) 64



Possibility of supernova neutrino detection, Astropart. Phys. 89 (2017) 51

Supernova at 10kpc



XMASSの有効体積解析の現状

■ XMASSの事象再構成

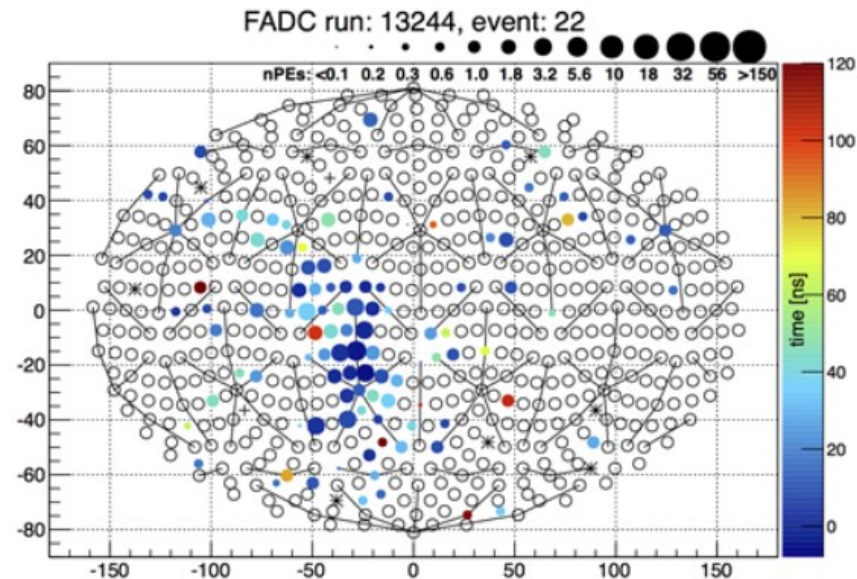
■ 「場所によって、検出する光量パターンに違いがある」ことを利用

■ $R(\text{PE}) < 20 \text{ cm}$ ($M=96.5 \text{ kg}$)

■ 検出器表面のBG事象を除くために、時間パターンの差も利用

■ $R(\text{T}) < 38 \text{ cm}$

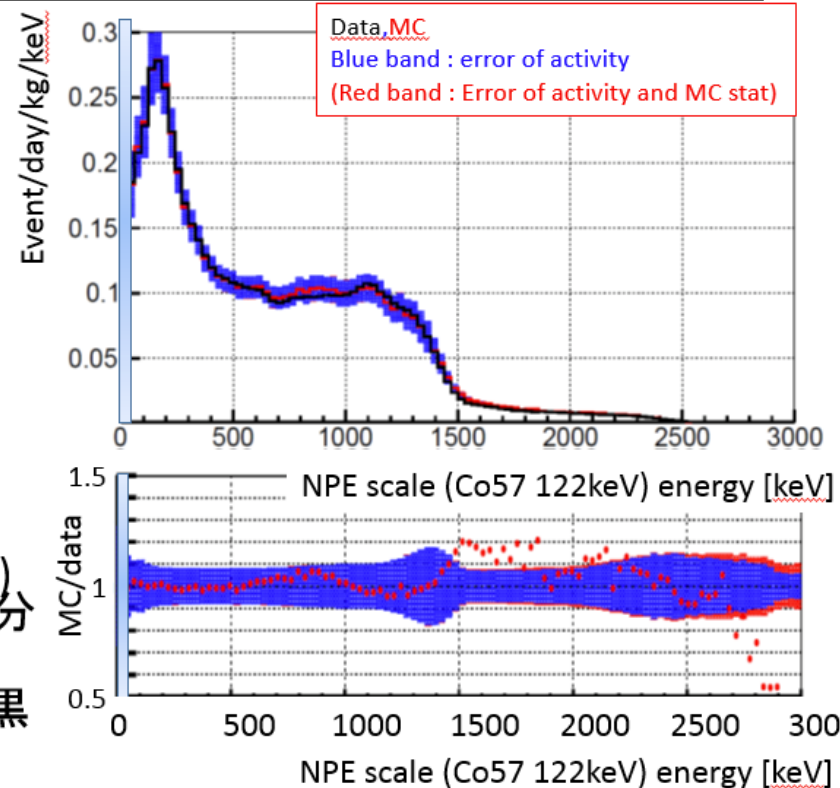
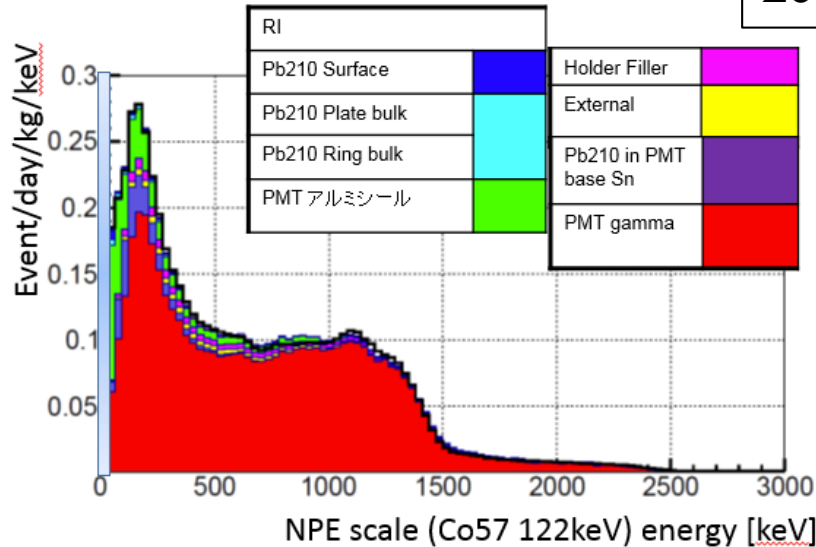
10 keV energy deposit by DM particle (MC)



有効体積解析 :

- 全体積でバックグラウンドを評価
- このバックグラウンドに有効体積カットをかける

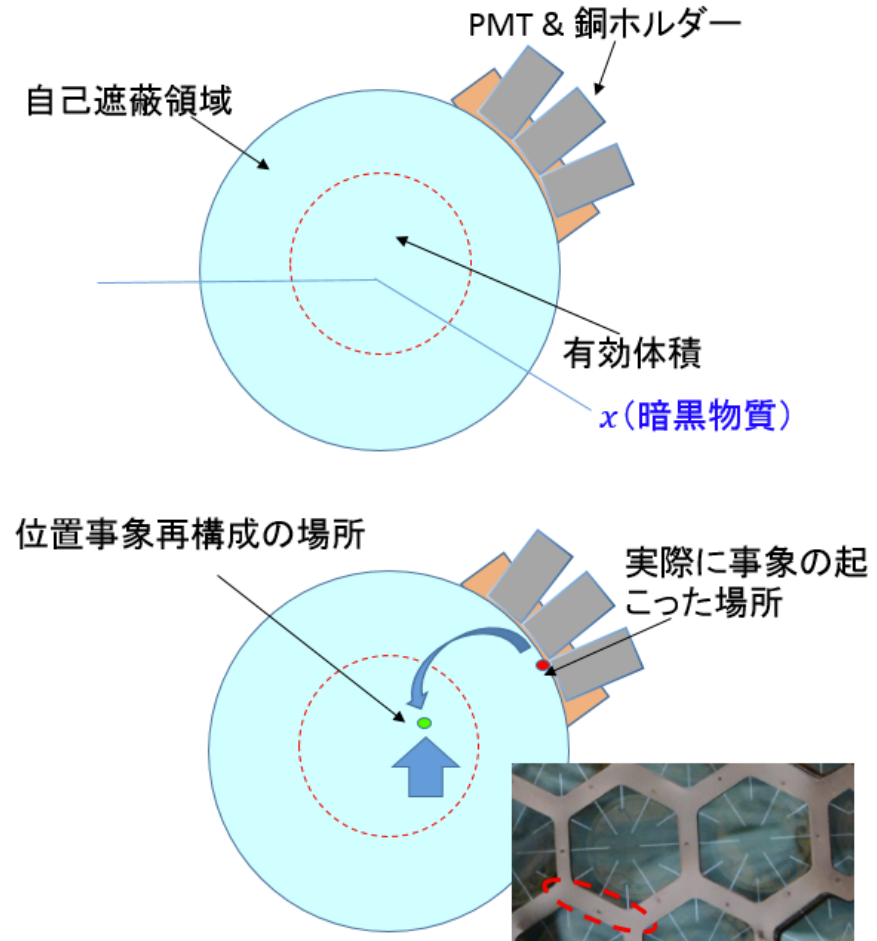
2016年秋の学会での小川さんのスライド



- 左図: fitで求めたRI activityのmean (右図の赤点) によるBGMCとdataのNPEスケールのエネルギー分布。有効体積カットはしていない。
- 右上図: fitで求めたRI activityの誤差 (右上図の黒線)を含むBGMCとdataのNPEスケールのエネルギー分布。有効体積カットはしていない。
- Fit後は、DataとMCの予想はよく一致している。
- 右下図: MC/dataの分布。1500~1800keV付近除いて誤差(青+赤)の範囲内である。

どのような事象が有効体積内に残るのか

- 壁ぎわ・隙間事象: ~90%
 - PMT死角部分で起こった事象が、PMTにより検出される光量分布が有効体積内事象と似てしまう。
 - 検出器銅表面・内部のPb210, 検出器部材からの γ が壁ぎわ・隙間で発光したもの。
 - ※銅内部のPb210含有: α カウンタの測定についてはJPS2016Mar報告済み(小林)
- 液体キセノン中のRI事象: ~10%
 - Rn222娘核種Pb214, Bi214や Kr85, Ar等
- 中性子起源: 少ない
 - 検出器部材の(α, n), fissionからの中性子
 - 詳細: 竹田



このBGに対する系統誤差の見積もりを慎重に行っている。

- 検出器Geometry (最大と見積もられる)
- Xenon の発光特性
- 事象再構成

近い将来に期待される成果

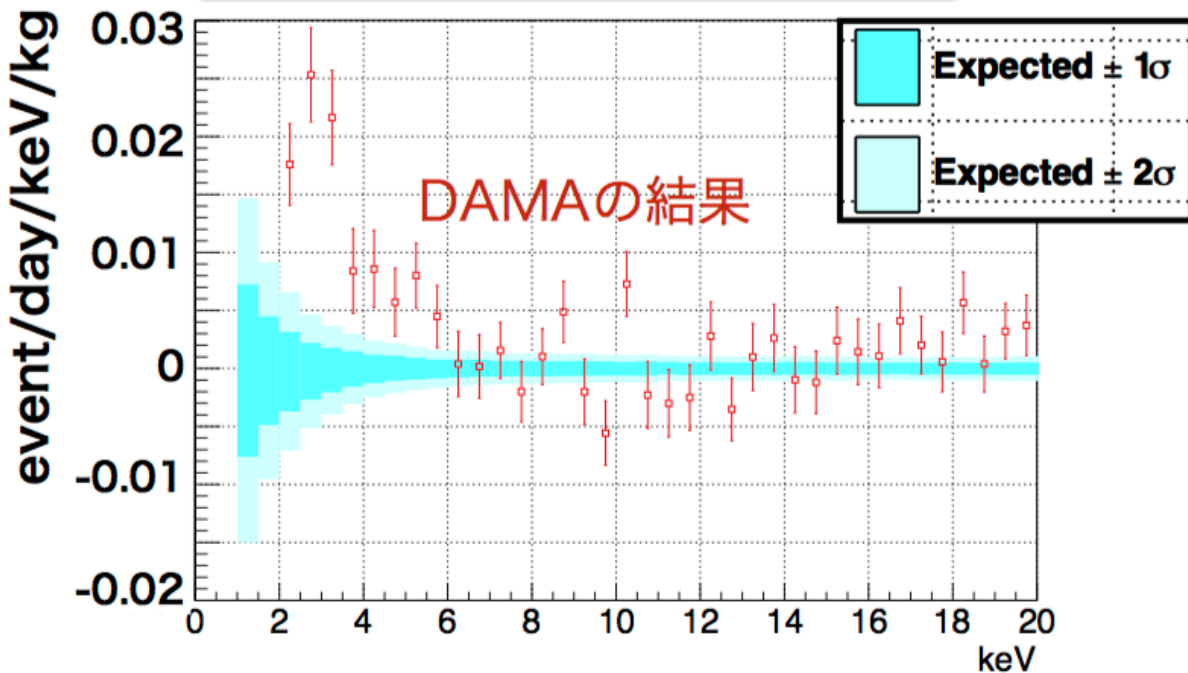
Annual modulation

- 345.5 d \rightarrow 787.7 d
- データがより安定
- (低閾値でのDAQ (2015年12月から))

pe/keV



Modulationがない場合に対する振幅の感度



DAMA/LIBRA claim の
全領域を追試

(申請時の公約の達成)

近い将来に期待される成果(Cont.)

- ▶ 有効体積解析による結果
- ▶ 二重電子捕獲反応探索のUpdate
- ▶ Super WIMPs 探索のUpdate
- ▶ KK-Axion 探索
- ▶ (銀河内の超新星爆発があれば) 超新星爆発 ν の観測
- ▶ など

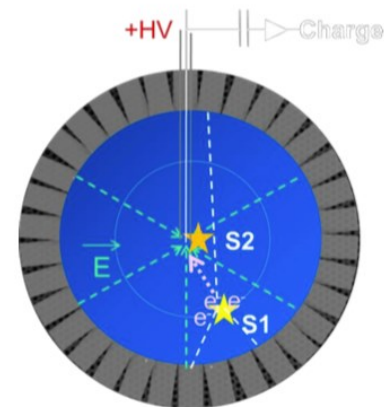
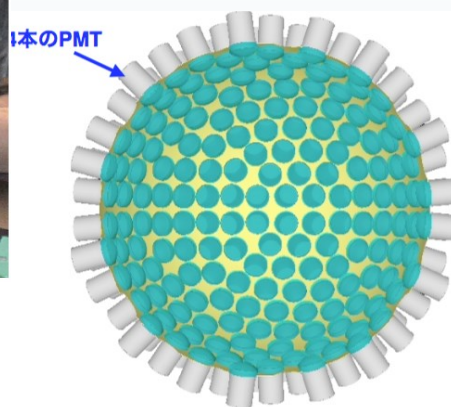
将来の低バックグラウンド検出器

新型3"凸型PMT開発



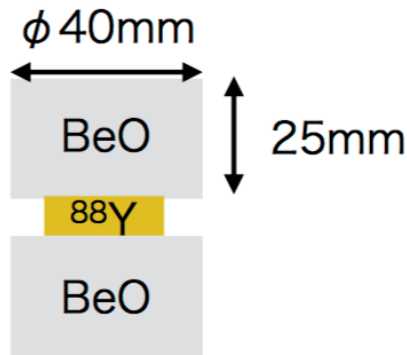
Geスクリーニング

検出器のデザイン

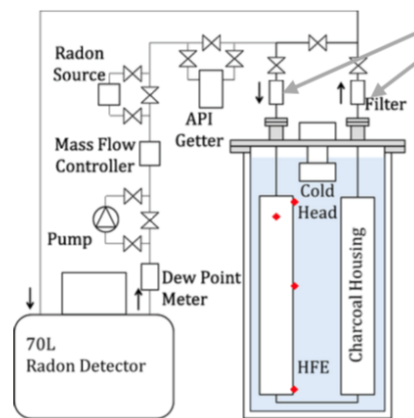


液体TPCの基礎研究

低エネルギー単色中性子線源



Rn対策フィルムの開発



液体キセノンからのRn除去



アルファ線検出器による表面測定と内部の鉛測定

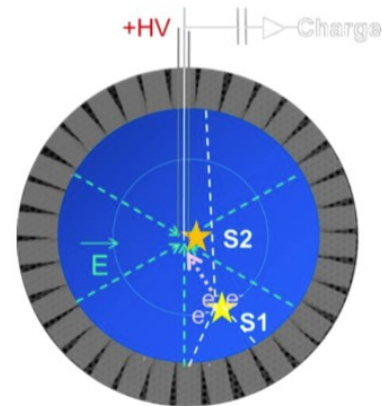
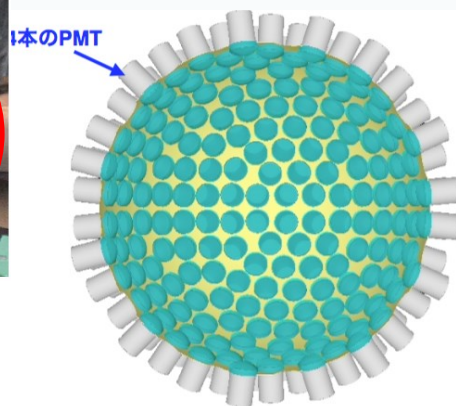
将来の低バックグラウンド検出器

新型3"凸型PMT開発



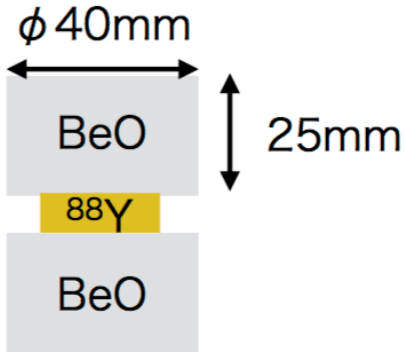
Geスクリーニング

検出器のデザイン

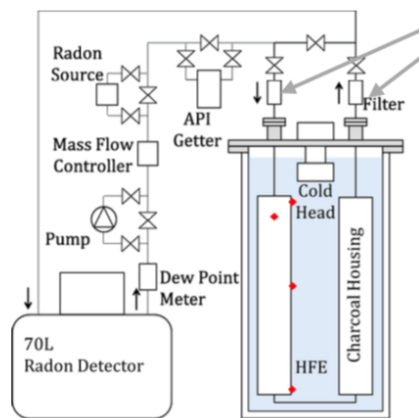


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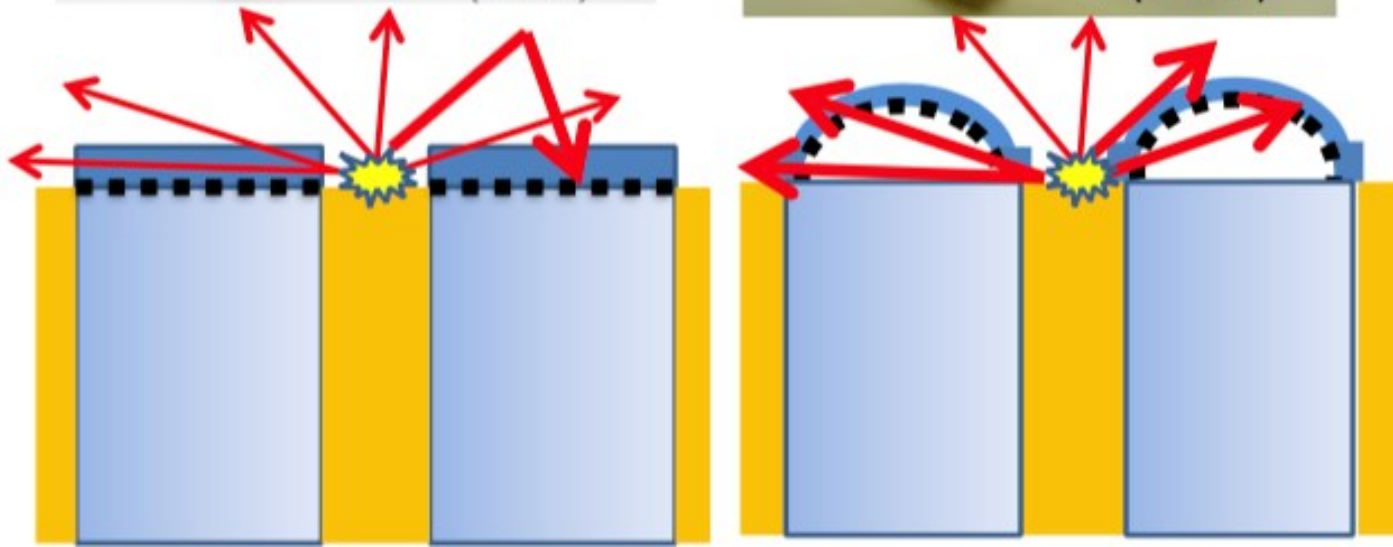
液体キセノンからのRn除去



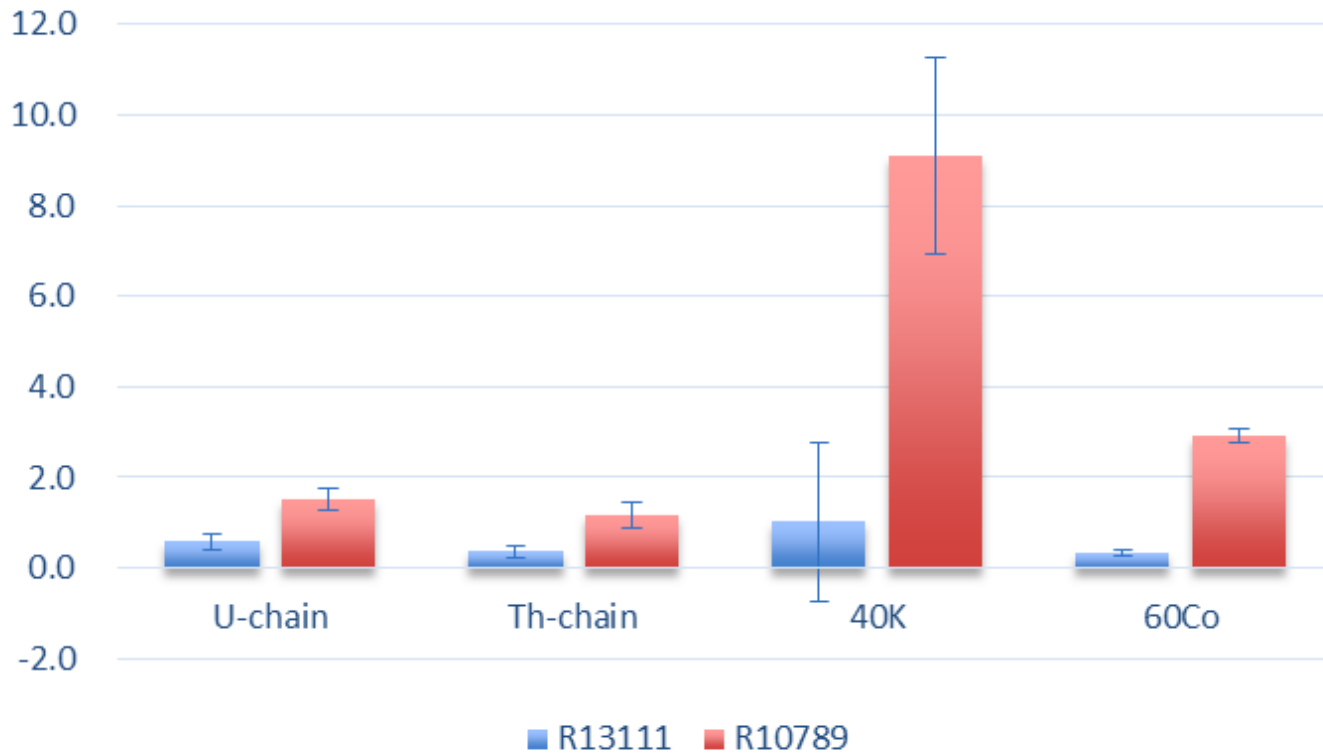
アルファ線検出器による表面測定と内部の鉛測定

新型 3"凸型PMT

- ▶ 超低バックグラウンド
- ▶ 新型 3"凸型PMT (R13111) で表面の事象を逃さない



R13111とR10789比較



[mBq/PMT]	U chain	Th chain	40K	60Co
Target	0.15		1.00	0.30
R13111	0.624±0.168	0.478±0.152	<1.24	0.478±0.0567
R10789	1.51±0.243	1.16±0.27	9.10±2.15	2.92±0.161

R 1 3 1 1 1

R 1 0 7 8 9



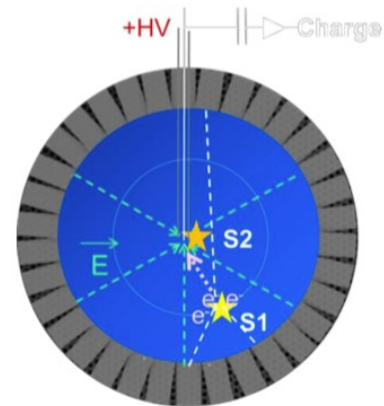
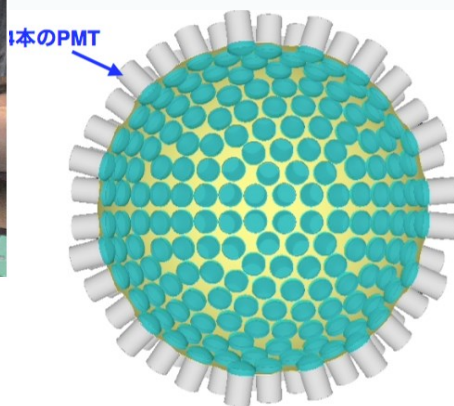
将来の低バックグラウンド検出器

新型3"凸型PMT開発



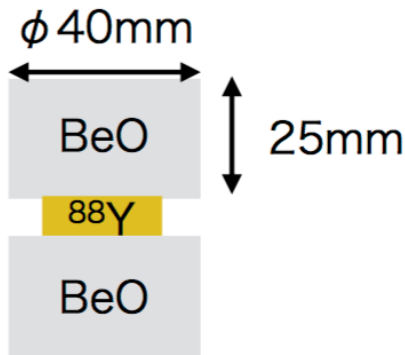
Geスクリーニング

検出器のデザイン

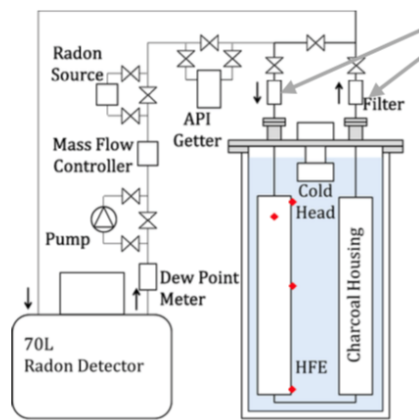


液体TPCの基礎研究

低エネルギー単色中性子線源



Rn対策フィルムの開発



液体キセノンからのRn除去

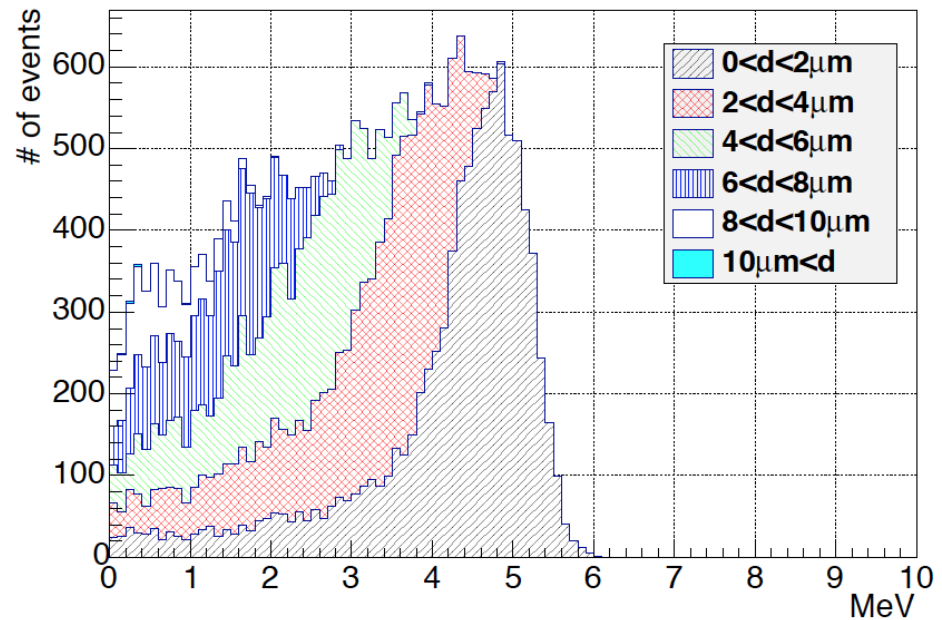


アルファ線検出器による表面測定と内部の鉛測定

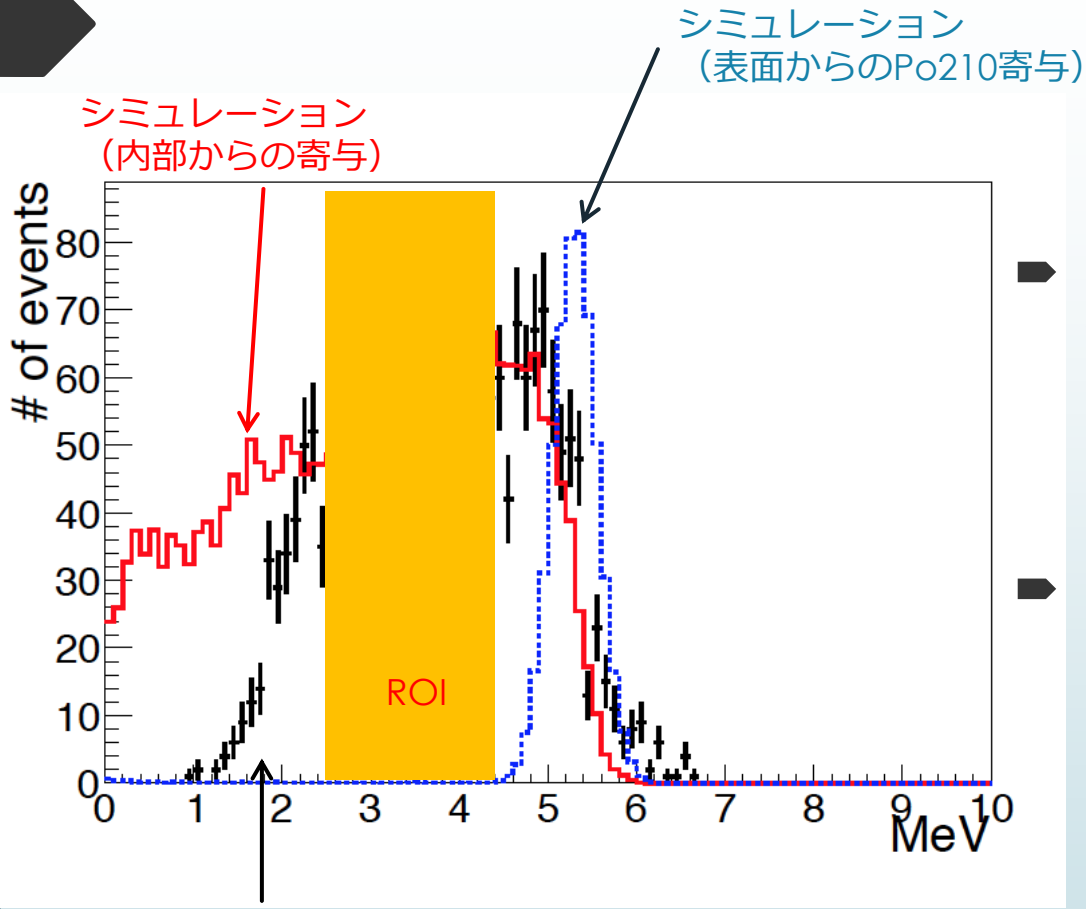
表面アルファ線検出器を用いた Cu内部の放射性鉛の微量測定



- ▶ アルファ線も短距離なら金属中も突き抜ける
- ▶ 電解研磨表面など滑らかな面の凹凸は、この距離より短い



内部からの (Po210の) アルファ線は、
表面α線ピーク位置から離れた場所に連続スペ
クトルをなす

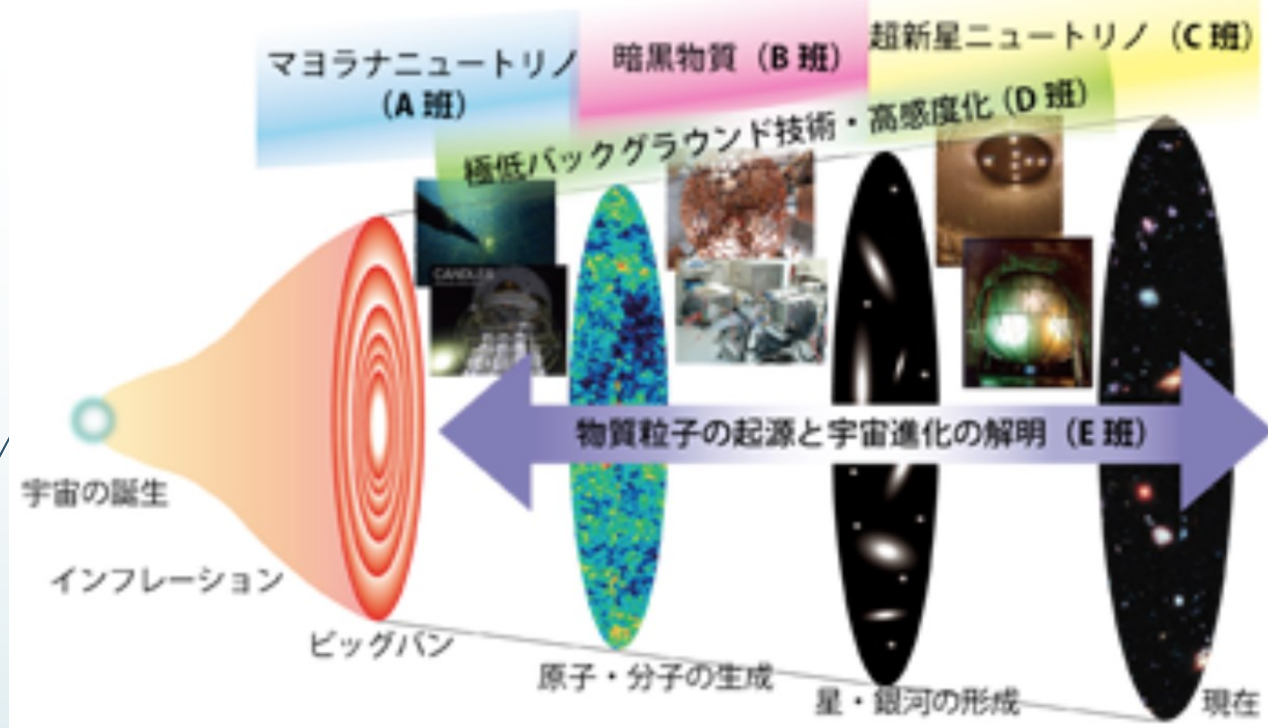


実データ
(2 MeV以下はEfficiencyの影響で下がっている)

- ▶ これまでにはない感度での含有鉛測定が可能
 - ▶ 数 mBq/kg

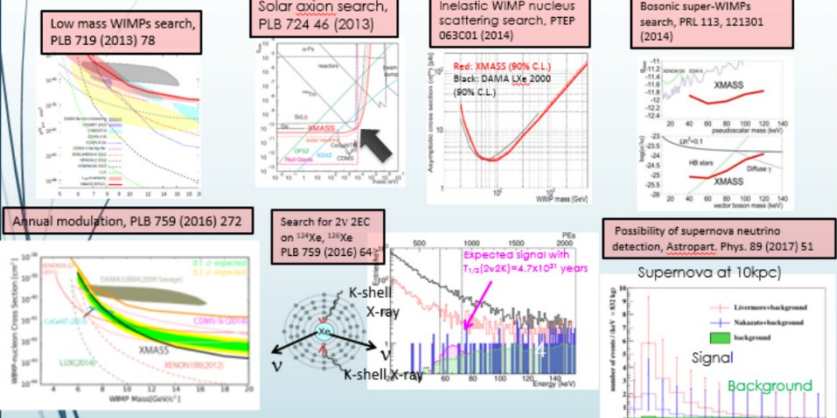
- ▶ 6 N 銅, 電鍍銅は非常にきれい
 - ▶ 上限値のみ
 - ▶ 6 N : $^{210}\text{Pb} < 4.0 \text{ mBq/kg}$
 - ▶ 電鍍 : $^{210}\text{Pb} < 2.8 \text{ mBq/kg}$

みなさん使ってください



XMASS physics results

Owing to low background for e/γ events (not only nuclear recoil), various kinds of dark matter candidates and physics topics have been searched for.



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φ40mm
 BeO
 88Y
 BeO
 25mm

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